Innovations

From Pixels to Perfection: 3D Printing in Endodontics

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Abstract

The only applications for 3D Printing technologies in the 1980s were the creation of aesthetically pleasing or functional prototypes. In today's world, the arena of possibilities that 3D printing has to offer has been so vast, that the field of dentistry has also dabbled in the likes of it. Through this review, we attempt to explore the transformative impact of 3 dimensional printing in endodontics, revolutionising the field by enhancing precision, efficiency, and patient outcomes. The key utilizations of 3D printing in endodontics include fabrication of anatomically accurate models for preoperative planning, which is beneficial for preclinical studies. By utilising patient-specific 3D-printed models, endodontists can meticulously analyse complex root canal anatomy, identify potential challenges, and develop tailored treatment strategies, ultimately improving treatment success rates. The utilisation of patient-specific guides enhances accuracy during access cavity preparation, canal shaping, and obturation, reducing the risk of iatrogenic errors and promoting optimal treatment outcomes. By drawing upon key studies from the literature, this review explores and discusses the plethora of applications provided to the field of Endodontics by 3D Printing.

1. Introduction

Neweradvents in digital technology and their application to dentistry, have resulted in theemergence of devices or techniques that can be used to enhance teaching and management of various treatment procedures. One of these techniques is 3D printing. Oxford dictionary describes 3D printing as "The process of making a physical object from a 3D 'digital model file' by laying down successive thin layers of a material" [1]. Today, 3D printing is used in many different countries. 3D printing technology is being used more and more in the automotive, locomotive, aviation, healthcare, and agricultural industries to build and modify open-source designs in large quantities. An object can be manufactured directly, layer by layer, from a computer-aided design (CAD) model using 3D printing technology.

Endodontics is a vital branch of dentistry that treats problems pertaining to the root canal system and dental pulp. Understanding and appreciating the internal root structure and tooth form is crucial for a successful endodontic therapy. The development of 3D printing technology has opened up new avenues for improving the accuracy and effectiveness of endodontic treatments[2]. Therefore, there has been a great deal of interest in the development of 3D imaging, 3D printing, and 3D virtual planning. The digital data is obtained using a surface scanner and cone-beam computed tomography (CBCT). A software application is then used to create and process the data. Then, using additive manufacturing techniques—which involve picking and selecting materials to cure or bind into successively fused vertical layers—the model is formed. Similar objects with complex geometric geometries and different cross-sectional forms, densities, colours, or mechanical qualities can be produced. [3]

2. 3D Printing Applications in Endodontics:

2.1. Guided Endodontic Access

The pulp survives mild trauma or immature tooth development and subsequently revascularizes, or heals, itself. Consequently, there is an increase in dentin deposition and pulp canal calcification (PCC) or obliteration (PCO). In addition, aging, orthodontic treatment, restorations, chronic caries, and critical pulp therapy procedures can all cause it [4].Endodontic therapy is only required in cases when pulp necrosis—a late PCC consequence that manifests years after the original diagnosis—is demonstrated clinically or radiographically [5]. Such canals must be located and navigated by an expert with anatomical knowledge, three-dimensional mental visualization, and an even hand to drill in the path in which the canal is anticipated to open. Significant tooth loss, perforations, canal distortion, and instrument separation could result from the access opening [6]. Because of this, a novel channeling technique, relying on the concepts and design of guided implant procedures was created for access cavity preparations which is apically extended [7]. It is known as guided or targeted endodontics, and it makes customized guides using 3D printing technology. Precise access cavity preparation up to the apical third of the root was made possible by "Guided Endodontics." In an in vitro study, Connert et al. [8] employed three operators with different degrees of expertise to evaluate a guided endodontic method compared to conventional access preparation. They concluded that, independent of skill level, guided therapeutical procedure allowed operators to discover 92% of canals, which is a statistically significant improvement over the conventional method's 42%. Therefore, guided endodontics is an approach with a lot of promise that minimizes chairside time and the risk of iatrogenic injury while offering an extraordinarily predictable result. [9].

2.2. Guided EndodonticMicrosurgery

Endodontic microsurgery (EMS) is a technique used to treat recurrent and persistent apical periodontitis when an orthograde approach to the apical region of the root canal is not practical. The success rate of EMS is now comparable to nonsurgical endodontic retreatment provided preoperative 3D scanning, a dental operating microscope, miniature instruments, ultrasonic root-end preparation tips, and calcium silicate materials are used [10]. However, based on the CBCT scans, it is difficult to directly localize the root apex intraorally, and freehand surgical techniques inevitably include a significant amount of bone resection. Because of the proximity of the neurovascular structure, additional surgical treatments in the mandibular posterior region are difficult. A 3D-printed surgical guide was produced, following the lead of guided implant surgeries, which enables the surgeon to do the complete surgical procedure by creating a small, targeted wound in otherwise difficult sections of the oral cavity. This approach is referred to as targeted or guided EMS [11, 12]. It minimizes surgical time and postoperative healing problems while guaranteeing accurate and conservative bone removal and root resection. Patel et al. (2017) used 3D printing for flap retraction as well [13]. The authors used a specially designed retractor based on diagnostic CBCT images to perform endodontic microsurgery on the maxillary left central incisor. During the procedure, the soft tissue handling and visualization were improved by the 3D printed retractor.

2.3. Tooth Models for Education, Training and Research

A crucial component of the dental cirriculum and the the postgraduate program in endodontics is pre-clinical training. It aids in the knowledge acquisition and hand skill development of the residents, which will benefit their clinical practice and lower the rate of iatrogenic errors. The primary component of pre-clinical exercises in endodontics and restorative dentistry continues to be the extracted natural tooth. However, there are limitations to this method. It includes limited obtainability, the potential for cross-infection, and variations in the shape of the root canal, which impede the implementation of standardized teaching and learning.

Rapid prototyping has been utilized in recent years to swiftly produce a scale replica of a physical part or assembly, using three-dimensional computer-aided design (CAD) data. 'Additive layer manufacturing', often known as 3D printing, is typically used to construct the part or assembly [14].Similar to this, scanning human teeth with a cone-beam computed tomography (CBCT) or micro-computed tomography (μCT) scan and then replicating them using a 3D printer simplifies the process of creating the fake tooth model. Similarly to 3D models that just depict the external features of the tooth, a hollow inside tooth model can also be produced using this technique. The shape of the pulp can be visualised by filling in the hollow interior areas with red ink. Such a 3D-printed model is attaining recognition for pre-clinical education globally. The benefits include realistic replication of the actual root canal structure, standardization of the morphology, visualization of internal anatomy, and ease of availability [15].According to a systematic analysis conducted by Decurcio et al., educational outcomes were comparable when using artificial 3D printed teeth for pre-clinical endodontic instruction as opposed to extracted teeth [16].

3D printed models are used in pre-clinical research to examine various rotary file systems' shaping ability [17] and stress values [18]. To print an in vitro model for irrigation technique evaluation [19, 20], 3D-printed models for pulpotomy, revitalisation, complex anatomy tooth for RCT and instrumentation separation can be designed to replicate the clinical experience for students and be used to mass produce teeth for destructive examination. Reconstructing difficult clinical instances including external invasive resorption, 3 distal rooted molar [22], displaced root [21], and Type 3dens invaginatus [23].Obturating C-shaped canals in pre-clinical research.[24]

2.4. Auto transplantation

For young individuals, tooth autotrans plantation is a feasible alternative for replacing a single tooth [25]. There is evidence that the teeth that were transplanted had a favorable long-term prognosis. The conservation of the periodontal ligament (PDL) cells and a satisfactory adjustment of the donor tooth at the recipient site are prerequisites for the treatment's efficacy. The amount of extraoral time and PDL trauma sustained during the surgery have a big effect on the result. The predictability of current auto transplantation techniques has risen with the incorporation of three-dimensional planning. Rapid prototyping and CBCT integration enable preoperative planning and the production of a donor tooth replica. To enhance the donor tooth's suitability and minimize the duration it remains outside the mouth, a replica of the recipient's socket is created initially. This replica is then utilized to prepare the alveolar socket before extracting the donor tooth, and it has proven to be effective in replacing both anterior and posterior teeth. Notably, mesiodens donor tooth was used to substitute a lateral incisor in Lee's case report in 2014 [26], while Cahuana Bartra utilized an ectopic premolar [27] and Shahbazian et al. inserted a premolar into a maxillary central incisor's alveolar socket [28] in 2020. Additionally, wisdom teeth have been employed to substitute first and second molars. Donor teeth can be printed using materials such as cobalt chrome and biocompatible resins, which has significantly reduced the time the donor tooth is outside of the mouth to less than a minute and increased the success rate of the procedure.

2.5 Regenerative Endodontics

In endodontics, the 3D printing principle can be used to deliver stem cells, pulp scaffolds, injectable calcium phosphates, growth factors, and gene therapy [29]. To imitate the milieu of the root canal and offer mechanical support, scaffolds utilized in regenerative dental pulp applications need to be optimized spatially and temporally for the best possible cell attachment and growth. There are several challenges associated with using traditional scaffolds, including low reproducibility and shape-related restrictions. It is possible to use three-dimensional (3D) bioprinting, a rapid prototyping process that builds complicated tissue models quickly from computer-aided design blueprints.With the use of this technology, it is possible to precisely manage the internal microstructure and surface morphology of scaffolds, as well as to distribute and regulate cell extensions and growth in the three-dimensional space of simulated tissue in vivo. Yu et al. found that 3D-printed Alg-Gel scaffolds were more favorable for cell adhesion and proliferation when comparing the growth of human dental pulp stem cells on Alg-Gel versus Alg-Gel scaffolds [30]. Pulp tissue can be substituted using 3D-printed cells. Layers of suspended cells can be dispensed into the hydrogel to replicate the structure of the pulp tissue. Because of this, the cells can be arranged exactly to resemble natural pulp tissue, with fibroblasts in the center and odontoblast-like cells on the periphery, encircled by a network of vascular and neural cells.

5. Conclusion:

There are several uses for 3D printing technology in endodontic patient treatment, education, and research. It has accelerated, stabilized, and improved the endodontic therapy’s safety. It enables virtual planning, which enhances the operator's competence before trying difficult processes. With this technology, human error is unlikely since careful preparation ensures precise execution. To fully utilize this technological innovation and raise the bar for patient care, the endodontist needs to be well-versed in it. As the technology develops, endodontic practice will probably undergo a revolution thanks to its widespread adoption, which will improve patient outcomes and clinical procedures.

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